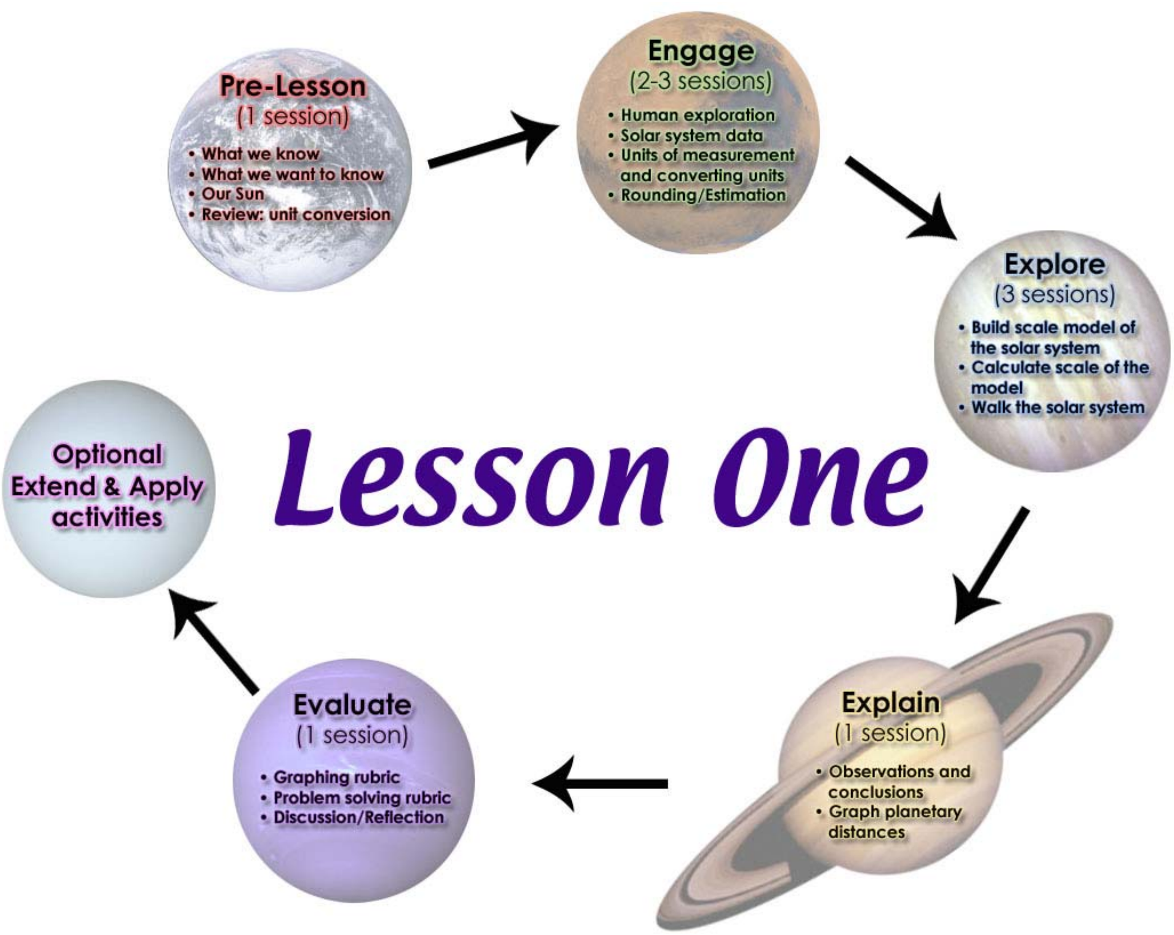
NASA Explorer Schools Pre-Algebra Unit

Lesson 1 Teacher Guide

Solar System Math

Comparing Size and Distance



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NOTE: A “session” is considered to be one 40-50 minute class period.

Solar System Math

Comparing Size and Distance

Lesson 1

What are the parts of the solar system and how do they compare?

Introduction

This lesson will introduce students to the solar system using the *What's the Difference* software application and will give students hands-on experience with measurement, unit conversion, rounding and estimation, calculating scale, and graphing data. Students will construct a scale model of the solar system in regard to size, and they will walk a scale model of the solar system in regard to distance. Using graphs and problem solving skills, students will reflect on the size and attributes of planets and moons in the solar system, calculate the scale of the distance model, and use what they have learned to refine their ideas about where in the solar system humans may be sent.

Lesson 1 – OBJECTIVES, SKILLS, & CONCEPTS

Main Concept

The Earth is the third planet from the Sun in a system that includes Earth's moon, eight other planets and their moons, and small bodies including asteroids and comets. These bodies all vary greatly in terms of their size and their distance from the Sun.

Instructional Objectives

During this lesson, students will:

- Gather information about the planets and moons in our solar system.
- Create a scale model of our solar system that includes distance from the Sun and the diameter (size) of the planets.
- Use ratio and proportion to compare the size of the scale model solar system to the actual size of our solar system.
- Describe the parts of our solar system in terms of size, distance, and location.
- Match appropriate units with given situations and convert units within a system of measurement (kilometers and Astronomical Units).
- Graph the distances from the planets to our Sun.

Major Focus Skills

Math topics covered in this lesson:

- Ratio and proportion
- Measurement with standard and metric units
- Unit conversion
- Scale
- Data analysis
- Problem solving

Major Focus Concepts

Math

- Measurement involves measurement tools and measurement units that have been determined by people.
- Different measurement tools and measurement units are used to measure different properties. (Example: rulers with centimeters or inches or yards are used to measure length.)

- Creating scale models often requires converting larger units to smaller units where the sizes remain proportional.

Science

- In our solar system, nine planets of different sizes move around the Sun in oval orbits that are known as elliptical orbits. These elliptical orbits are very close to being circular orbits, so in order to make our calculations easier, we will assume that the orbits are circular.
- The sizes of all of the planets vary greatly and the distances between them are so great, that it is difficult to develop a small-scale model of size and distance at the same time.
- The paths of most planets around our Sun do not vary that much, which means that their orbits are nearly circular.
- Since each of the planets orbits the Sun at a different rate, the planets' distances from each other at any given time vary a great deal.

Prerequisite Skills and Concepts

Math Skills

- Addition and subtraction of decimals
- Multiplication of multiple digit numbers and decimal numbers
- Multiplication and division by powers of 10
- Customary and metric units of measurement and unit conversion
- Understanding ratios (a comparison between two numbers sometimes written as a fraction)
- Solving for unknown variables and using ratios and proportions
- Basic calculator skills (multiplication and division of large numbers)

Science Concepts

- A star system is one or more stars and the objects that orbit the star(s).
- Our Sun is a star.
- A star is a large, hot ball of gases that gives off its own light.
- A planet is a body that orbits a star and does not give off its own light. A planet is generally much smaller than a star and can be made of solid, liquid, and/or gas materials.
- There are nine planets orbiting our Sun (Inner planets: Mercury, Venus, Earth, Mars / Outer planets: Jupiter, Saturn, Uranus, Neptune, Pluto).
- A moon is a natural satellite that orbits a larger object, like a planet or asteroid.
- There are asteroids orbiting the Sun in a region between the inner and outer planets.
- Asteroids are rock and metallic objects that orbit the Sun, but are too small to be considered planets.

NATIONAL EDUCATION STANDARDS		
Fully Met	**Partially Met**	**Addressed**
NCTM (3-5) Measurement #1.2 (3-5) Data Analysis and Probability #1.3 (6-8) Number and Operations # 1.4 (6-8) Measurement #2.5 Problem Solving # 1 Problem Solving #2 Communication #2 Connections #3	NCTM (3-5) Measurement #1.1 (3-5) Measurement #1.4 (3-5) Measurement #2.2 (3-5) Data Analysis and Probability #1.1 (6-8) Measurement #1.1 (6-8) Measurement #1.2 (6-8) Measurement #2.2 (6-8) Data Analysis and Probability #1.1 (6-8) Data Analysis and Probability #1.2 2061 4A (6-8) #3 NSES D (5-8) 3.1	NCTM (6-8) Number and Operations #1.5 (6-8) Measurement #1.3

SW = student workbook TG = teacher guide EG = educator guide

Lesson 1 – PRE-LESSON ACTIVITY

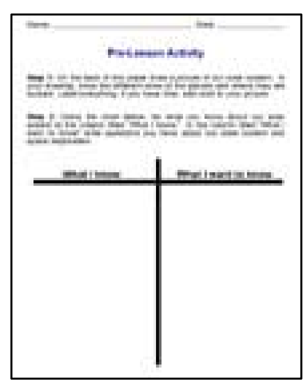
- **Estimated Time:** 1 session, 30–40 minutes
- Materials:
  - Pre-Lesson Activity (SW p.2)
  - Drawing materials (crayons, colored pencils, markers)
  - Rulers
  - Transparency #1: The Sun (TG p.9)
  - [Optional] computer with Internet connection
  - [Optional] Math Review: Converting Units Teacher Resource (TG pp.10-16)
  - [Optional] Math Review: Converting Units Student Practice (SW p.3)

This activity is a good way to find out where students are in terms of their basic knowledge of the solar system before beginning the lesson.

First, discuss with students the basic properties of our solar system. They should know that it includes the Sun and the planets that travel around (orbit) the Sun. Earth is one of those planets.

Next, hand out the Pre-Lesson Activity worksheet (SW p.2). Using the back of the worksheet, ask students to draw the solar system from what they already know. Tell them to be as accurate as possible with regard to how large they make the planets and how far away the planets are from the Sun. They need to label *everything*. If you have the time and materials, ask your students to include color in their picture.

> **Note:** Inform students that this is NOT a test or an assessment. This activity will show what students already know about the solar system, and it will be a great way to see what they have learned at the end of the lesson.



After students have completed their drawings, tell them to list everything they know about the solar system in the column titled “What I know.” In the column titled “What I want to know,” have them list their questions about the solar system, the planets, and space exploration. Encourage students to list at least 5–6 items in each column because the more creative questions often come after the first few.

Note: It can be helpful to have students discuss their questions as a class or in small groups; however, it is better if they do not share pictures or information at this time. By sharing their questions with each other, the discussion may spark deeper or more creative questions from students who are uncertain about what questions to ask.

Collect the drawings at the end of the activity. This will be a great way to see what your students know (or do not know) about our solar system as well as alert you to any false information they might have. It will also be helpful to see what questions the students have and what areas they will be most interested in during the lesson or unit. These drawings will be used again in the EVALUATE portion of the lesson.

Be sure students understand the nature of the Sun before beginning the lesson. It might be helpful to show your students solar images at http://sohowww.nascom.nasa.gov/ (Click on “Best of SOHO” under the DATA menu). **Transparency #1: The Sun** is one of the images from the SOHO web site. (TG p.9)

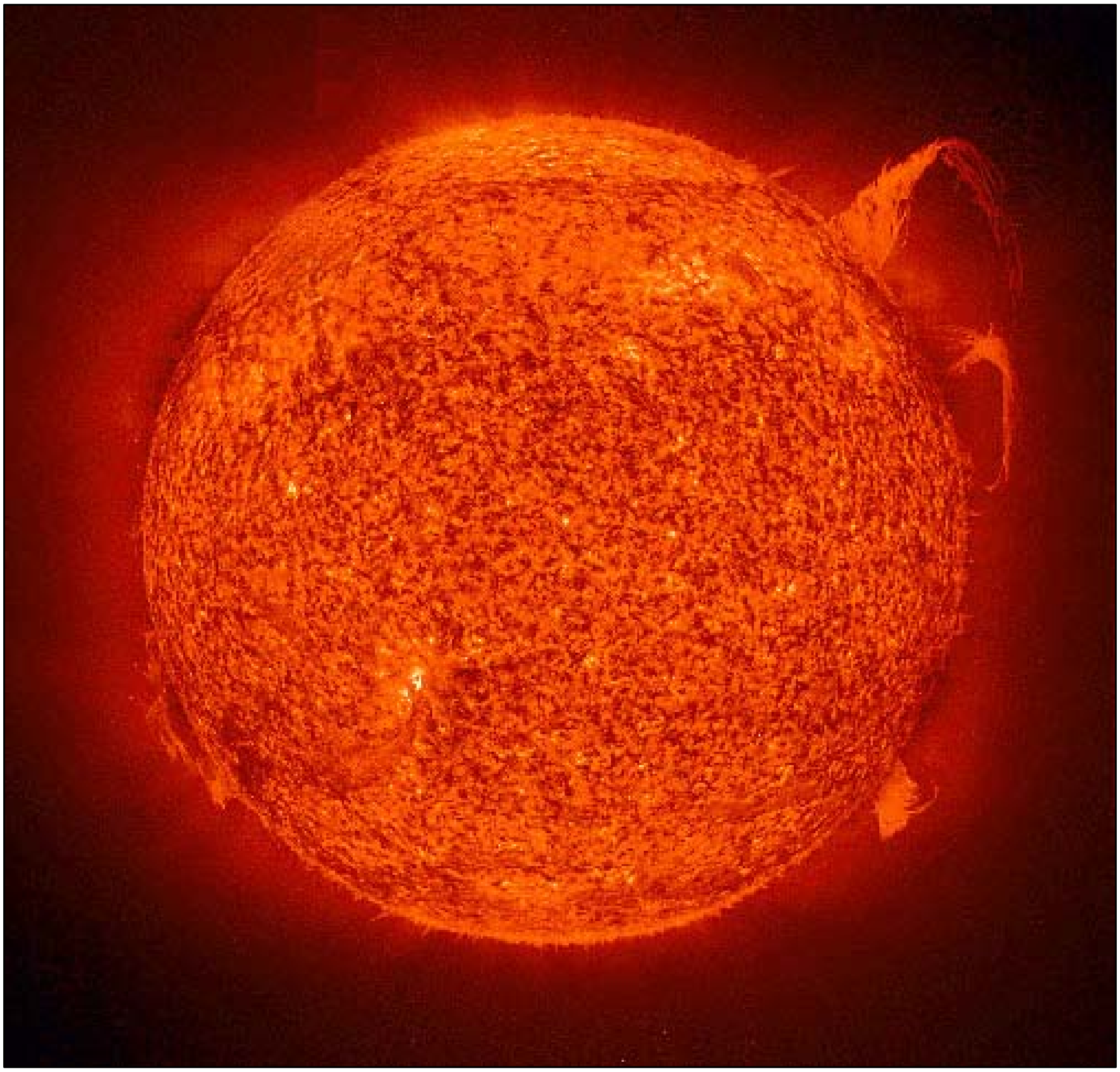
Misconception Alert! – Stars and planets

Due to the fact that the Sun is so close, some students have a hard time recognizing that our sun is actually a star. Some students may believe that the Sun is a planet and show this in their picture. It is important that the students understand that the Sun is a star—the source of light and heat for the solar system. To help students with this concept, ask them what the Sun would look like from *very* far away—maybe as if they were past Pluto and getting further away. (If students have a hard time visualizing this, you can model the idea with a flashlight.) Next ask them what other stars, like the North Star (Polaris), would look like if they were very close. Ask them to think about the differences between a planet and a star. It is important that they understand that the Sun is a hot ball of burning gases, like all other stars. Our Sun looks different because we are much closer to it than other stars. Even if we traveled at the speed of light (a speed we cannot even come close to), it would take us over four years to reach the next closest star (Proxima Centauri).

Math Review: Converting Units (optional)

Students need to be able to use multiplication and division to convert among different units of measurement. They also need to be able to set up conversion problems using a table of conversion factors or unit ratios. This skill is addressed in **Math Review: Converting Units.** (TG pp.10-16) This optional intervention lesson provides step-by-step instruction and multiple examples, along with practice problems and a table of conversion factors.

Transparency #1: The Sun



Our sun is a star—a hot ball of burning gases that provides heat and light to our solar system.

How do you think our Sun would look from very far away?

Math Review: Converting Units

Teacher Resource

In everyday life, we often need to convert from one unit to another unit. To do so, we can use **unit ratios**. When using unit ratios, we multiply to change one unit into another unit. This resource contains three sample problems for teachers to use as a demonstration in the classroom.

SAMPLE PROBLEM 1: How many inches are in 47 feet?

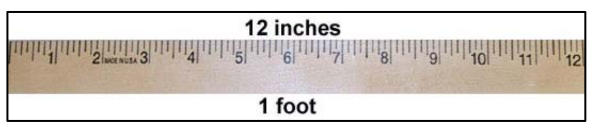
Equation: 47 feet = __ inches

Step 1: Identify the relationship between the unit you HAVE and the unit you WANT.

Relationship: 1 foot = 12 inches

Step 2: Write the relationship as a ratio with the unit you HAVE (in this case, feet) in the denominator. We start with 47 feet, so feet (or foot) are in the denominator.

Unit Ratio: $\frac{12 \text{ inches}}{1 \text{ foot}}$



This is the unit ratio you will use to solve the problem. *Note that 12 inches is equal to 1 foot, so this ratio is actually equal to 1.*

Step 3: Multiply the number you have (47 feet) by the unit ratio.

$$= \frac{47 \text{ feet}}{1} \bullet \frac{12 \text{ inches}}{1 \text{ foot}}$$

Step 4: When you multiply, the unit you HAVE (feet) will cancel and you will be left with the unit you WANT (inches).

$$= \frac{47\ \cancel{\text{feet}}}{1} \bullet \frac{12\ \text{inches}}{1\ \cancel{\text{foot}}}$$

Step 5: Multiply the numerators and the denominators.

$$= \frac{47 \bullet 12\ \text{inches}}{1 \bullet 1}$$

$$= \frac{564\ \text{inches}}{1}$$

Step 6: State your answer.

Answer: 47 feet = 564 inches

Note: Because you multiplied by 1, you did not change the distance that you measured; you only changed the unit.

47 feet = 564 inches

|--|

47 feet

|--|

564 inches

Sample Problem 2: How many miles are in 8,000 feet?

Equation: 8,000 feet = __ miles

Step 1: Identify the relationship between the unit you HAVE and the unit you WANT.

Relationship: 1 mile = 5,280 feet

Step 2: Write the relationship as a ratio with the unit you HAVE (in this case, feet) in the denominator. We start with 8,000 feet, so feet are in the denominator.

Unit Ratio: $\dfrac{\text{1 mile}}{\text{5,280 feet}}$

This is the unit ratio you will use to solve the problem. *Note that 1 mile is equal to 5,280 feet, so this ratio is actually equal to 1.*

Step 3: Multiply the number you have (8,000 feet) by the unit ratio.

$$\frac{\text{8,000 feet}}{1} \bullet \frac{\text{1 mile}}{\text{5,280 feet}}$$

Step 4: When you multiply, the unit you HAVE (feet) will cancel and you will be left with the unit you WANT (miles).

$$\frac{\text{8,000 } \cancel{\text{feet}}}{1} \bullet \frac{\text{1 mile}}{\text{5,280 } \cancel{\text{feet}}}$$

Step 5: Multiply the numerators and the denominators.

$$\frac{\text{8,000} \bullet \text{1 mile}}{\text{5,280} \bullet 1} = \frac{\text{8,000 miles}}{\text{5,280}}$$

Step 6: State your answer: *8,000 feet = 1.515 miles*

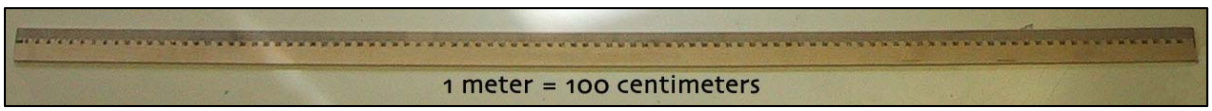
Sometimes you may need more than one unit ratio to change units.

Sample Problem 3a: How many inches are in 20 meters?

Equation: 20 meters = __ inches

Step 1: One approach is to first change meters to centimeters and then change centimeters to inches. We will first use the relationship 1 meter = 100 centimeters to change from meters (m) to centimeters (cm).

Relationship: 1 m = 100 cm



Step 2: Write the relationship as a ratio with the unit you HAVE (in this case, meters) in the denominator. We start with 20 meters, so meters are in the denominator.

Unit Ratio: $\frac{100 \text{ cm}}{1 \text{ m}}$

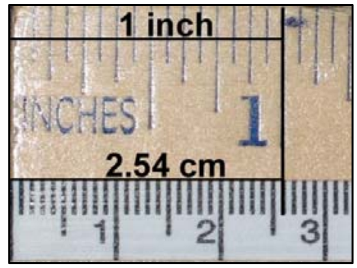
This is the **first** unit ratio you will use to begin converting meters to inches. *Note that 1 m is equal to 100 cm, so this ratio is actually equal to 1.*

Step 3: Multiply the number you have (20 meters) by the unit ratio.

$$\frac{20 \text{ m}}{1} \bullet \frac{100 \text{ cm}}{1 \text{m}}$$

Step 4: When you multiply, the unit you HAVE (meters) will cancel and you will be left with the unit you WANT (centimeters).

$$\frac{20 \cancel{\text{m}}}{1} \bullet \frac{100 \text{ cm}}{1 \cancel{\text{m}}}$$



Step 5: Multiply the numerators and the denominators.

$$\frac{20 \cdot 100 \text{ cm}}{1 \cdot 1} = 2{,}000 \text{ cm}$$

Step 6: Now we will use the *approximated* relationship 2.54 centimeters = 1 inch to change from centimeters (cm) to inches (in).

Relationship: 2.54 cm ≈ 1 in

Step 7: Write the relationship as a ratio with the unit you HAVE (in this case, centimeters) in the denominator. We start with 2,000 centimeters, so centimeters are in the denominator.

Unit Ratio: $\frac{1 \text{ in}}{2.54 \text{ cm}}$

This is the **second** unit ratio you will use to convert meters to inches. *Note that 1 inch is approximately equal to 2.54 cm, so this ratio is actually equal to 1.*

Step 8: Multiply the number you have (2,000 centimeters) by the unit ratio.

$$\frac{2{,}000 \text{ cm}}{1} \cdot \frac{1 \text{ in}}{2.54 \text{ cm}}$$

Step 9: When you multiply, the unit you HAVE (centimeters) will cancel and you will be left with the unit you WANT (inches).

$$\frac{2{,}000 \cancel{\text{cm}}}{1} \cdot \frac{1 \text{ in}}{2.54 \cancel{\text{cm}}}$$

Step 10: Multiply the numerators and the denominators.

$$\frac{2{,}000 \cdot 1 \text{ in}}{1 \cdot 2.54} = \frac{2{,}000 \text{ in}}{2.54} \approx 787.4 \text{ in}$$

Step 11: State your answer: *20 meters* ≈ *787 inches*

When you get really good at converting from one unit to another unit using unit ratios, then you can solve this problem using two unit ratios at the same time.

Sample Problem 3b: How many inches are in 20 meters?

Equation: 20 meters = __ inches

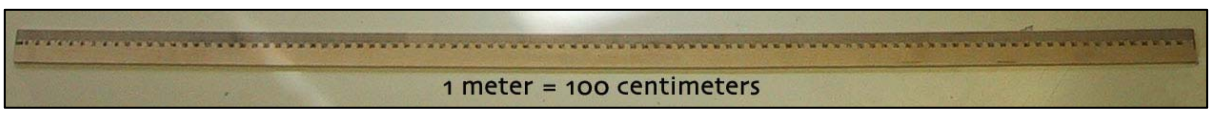
Step 1: Identify the relationships between the units you HAVE and the units you WANT.

Relationship A: 1 m = 100 cm

Relationship B: 2.54 cm ≈ 1 in

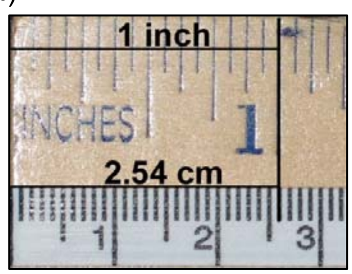
Step 2: Write the relationships as ratios. First we change meters (m) to centimeters (cm), so for the first unit ratio, meters is in the denominator.

Unit Ratio A: $\frac{100\text{ cm}}{1\text{ m}}$



Next we change centimeters (cm) to inches (in), so for the second unit ratio, centimeters is in the denominator. (Remember this is an *approximated* unit ratio.)

Unit Ratio B: $\frac{1\text{ in}}{2.54\text{ cm}}$



Step 3: Multiply the number you have (20 meters) by the unit ratios.

$$\frac{20\text{ m}}{1} \bullet \frac{100\text{ cm}}{1\text{m}} \bullet \frac{1\text{ in}}{2.54\text{ cm}}$$

Step 4: When you multiply, the units you HAVE (meters and centimeters) will cancel and you will be left with the unit you WANT (inches).

$$\frac{20\ \cancel{m}}{1} \bullet \frac{100\ \cancel{cm}}{1\cancel{m}} \bullet \frac{1\ in}{2.54\ \cancel{cm}}$$

Step 5: Multiply the numerators and the denominators.

$$\frac{20 \bullet 100 \bullet 1\ in}{1 \bullet 1 \bullet 2.54}$$

$$\approx \frac{2{,}000\ in}{2.54}$$

$$\approx 787.4\ in$$

Step 6: State your answer.

Answer: 20 meters ≈ 787 inches

SW = student workbook   TG = teacher guide   EG = educator guide

Lesson 1 – ENGAGE

- **Estimated Time**: 2-3 sessions, 40 minutes each
- Materials:
  - Travel Planning / Space Exploration worksheet (SW p.4)
  - Our Solar System worksheet (SW p.5)
  - Transparency #2: Side View of the Solar System (TG p.21)
  - Transparency #3: Top View of the Solar System (TG p.22)
  - Several computers with *What's the Difference: Solar System* dataset
  - Lesson 1 Planet Data Sheets (SW pp. 6-7) for each student and one on butcher paper or transparency for whole-class use
  - *A Brief History of Units of Measurement* article and questions (SW pp.8-10)
  - Unit Conversion: Building the Concept worksheet (SW p.11)
  - Unit Conversion: Applying the Concept worksheet (SW p.12)
  - Rulers
  - Poster board or butcher paper
  - Transparency #4: Astronomical Units (TG p.26)
  - Unit Conversion: Using Unit Ratios Sample Problem worksheet (SW pp.13-14)
  - Helping Students Communicate Math—Teacher's Resource (EG pp.xx)
  - [Optional] Calculators

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1. SENDING HUMANS INTO OUR SOLAR SYSTEM

Before beginning the lesson, it is important to address the overall goal of the Solar System Math unit and how it relates to current events in NASA programs:

> **Goal:** *Select a planet or moon that is well suited for human exploration based on key attributes such as size, distance from the Earth, composition, and minimum mission duration. (Lesson 1 focuses on size and distance.)*


Travel Planning

Space Exploration

I. Connect a real-life situation to the task students will be completing

Help students draw on their prior experience to make a connection to the new topic. Using questions 1 and 2 on the "Travel Planning" portion of the student worksheet (SW p.4), ask students to imagine they are planning a family vacation and then guide them in a class discussion based on their responses.

II. Discuss the importance and benefits of human space exploration

Humans have always been driven to explore. Recently NASA announced its new human exploration mission. Using the Moon as a stepping-stone, NASA will eventually send people to explore further regions of our solar system, like Mars. This will be a long journey that will take decades. Robots will be sent first, but humans are the ultimate goal.

Through exploration, NASA seeks the answers to many fundamental questions. How did we get here? Are we alone? Where are we going? The U.S. is a nation of explorers and we want to learn and discover more. Finding the answers to scientific questions helps us to better understand our own planet and ourselves.

Using questions 3 and 4 on the “Space Exploration” portion of the student worksheet (SW p.4), lead students in a discussion about the importance and benefits of human space exploration.

2. INTRODUCTION TO THE SOLAR SYSTEM

The students' goal is to determine the best place(s) in our solar system to send humans. There are many challenges in planning a mission such as this. Just as if they were planning a family vacation, students need some important information before they make their decision and some math skills that will help them gather and understand their information. Before students decide where to go in the solar system, they will first gather some facts about the planets.

Notes:

1. There are many mnemonic devices to help students remember the names of the planets in order. One is My Very Educated Mother Just Served Us Nine Pizzas.

*2. In August 2006, Pluto was reclassified as a "dwarf planet," a decision that continues to be debated. Despite this re-classification, Pluto remains a key component of this lesson because it is still a body in our solar system that could be considered for human exploration.

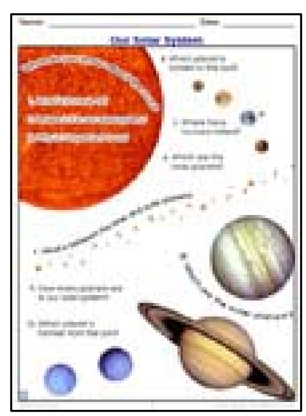
*3. At the time of this writing, NASA announced that a tenth planet in the solar system had been discovered. This planet is larger than Pluto and is approximately 97 AU from the Sun. It is not included in these lessons, but students may want to keep the planet in mind, as it is over two times Pluto's distance from the Sun.

I. Activate students' prior knowledge of the solar system

First host a class discussion using the questions on the "Our Solar System" worksheet. (*Refer to Prerequisite Science Concepts on page 5.*)

Misconception Alert! – Mars exploration

Students might think that humans have visited Mars. Remind them that we have sent unmanned rovers to explore the surface of Mars, but no humans have been to Mars. Humans have orbited the Earth and landed on the Moon. The last mission to land on the Moon was Apollo 17 in 1972.



II. Discuss planetary orbits

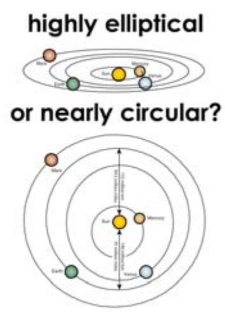
Next, show students **Transparency #2: Side View of the Solar System** (TG p.21), and ask how many of them have seen a picture such as this representing the solar system. Then show students **Transparency #3: Top View of the Solar System** (TG p.22). Discuss which picture presents a better view of the solar system.

Transparency #2 and #3 discussion questions:

- What are the advantages and disadvantages of each picture?
- What is wrong with the side-view picture?
- How might someone get the wrong idea from that representation?
- From the top-view, what can you tell about the planets' orbits?
- As a planet revolves around the Sun, does its distance from the Sun ever change dramatically?

Misconception Alert! – Planetary orbits

Most texts show solar system diagrams from a side view. This causes many students (and adults) to think that the planets revolve around the Sun in highly elliptical orbits. This may be how several students showed the solar system in their pre-lesson picture. It is important that students realize that although the planets travel in elliptical orbits around the Sun, most of the planets actually travel in nearly circular orbits and their distances from the Sun remain relatively constant.



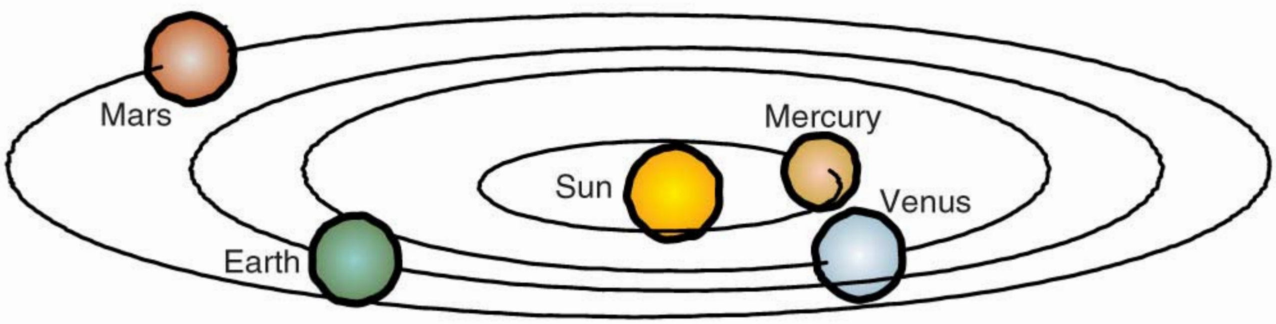
III. View the real time planetary positions

You can view the positions of the planets in real time at http://space.jpl.nasa.gov/. Select Show Me "The Solar System" as seen from "above." It is also helpful to select the "orbits" and "extra brightness" options above the "Run Simulator" button. To view the inner planets, select I want a field of view of "5" degrees. For the outer planets, select "45" degrees.

Misconception Alert! – Orbits and seasons

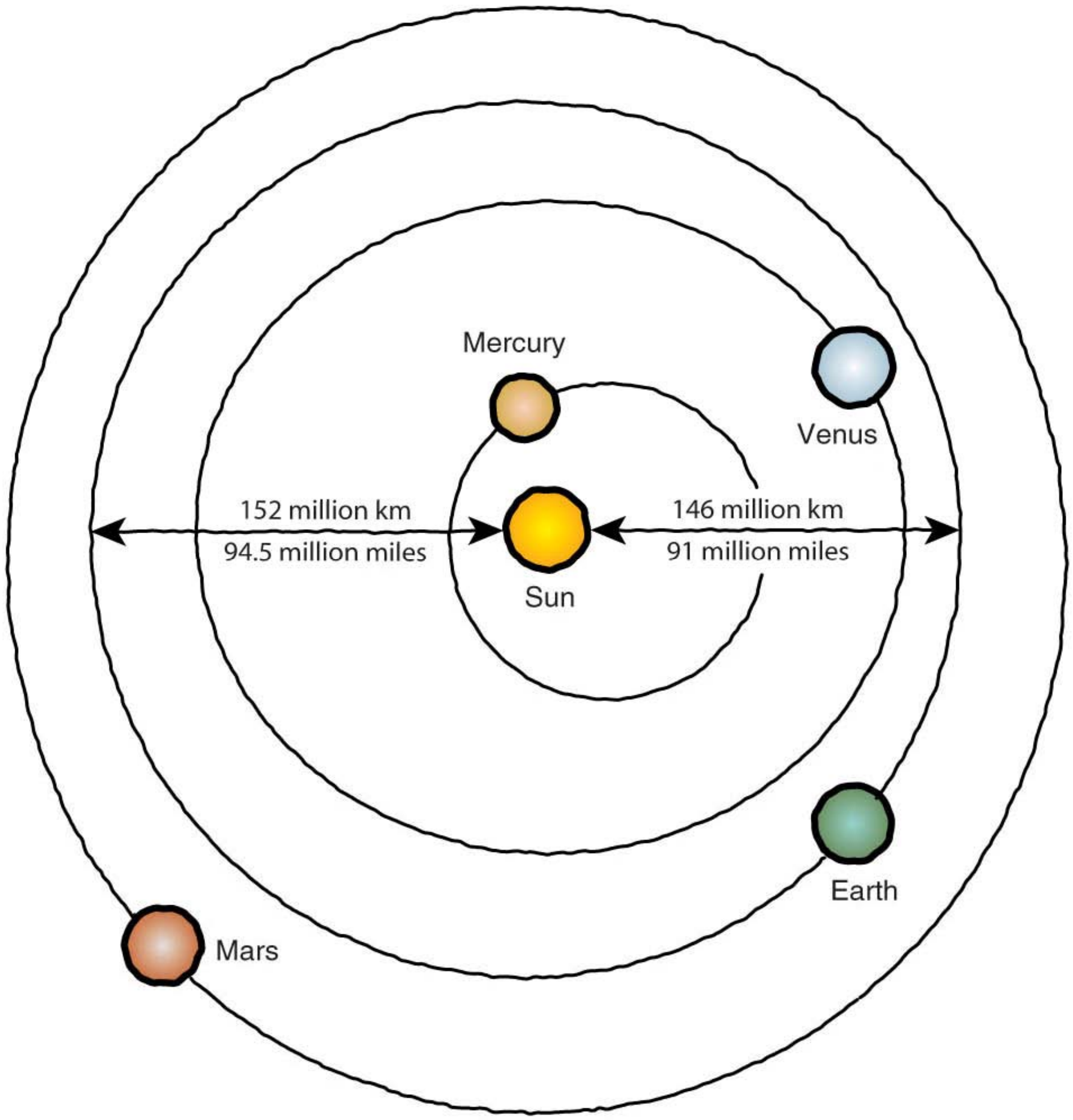
The misconception of highly elliptical planetary orbits also contributes to the misconception that the seasons are caused by the planet's changing distance from the Sun at different points during its orbit. For example, students may conclude that a planet is experiencing winter because it is at a point furthest from the Sun. In actuality, Earth's northern hemisphere experiences winter when Earth is closer to the Sun and summer when it is furthest from the Sun. Helping students to understand that the planets are in nearly circular orbits will help to overcome this misconception.

Transparency #2: Side View of the Solar System



Planet and Sun sizes not to scale.

Transparency #3: Top View of the Solar System



Planet and Sun sizes not to scale.

<u>IV. Data Collection Using *What's the Difference*</u>

Students will use the “Solar System” dataset in *What's the Difference* (WTD) to gather data about the solar system. Ask students what information they need to know about the planets and moons before they decide where to send humans. Try to guide their responses to appropriate factors, like how far away a planet or moon is, how big it is, what it is made of, how hot or cold it is, what the atmosphere is like, etc.

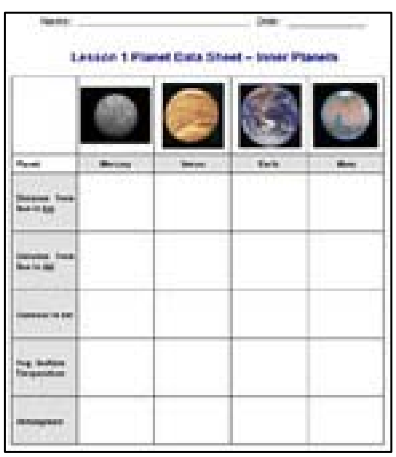
Demonstrate to students how to use the WTD tool. Students will use WTD to gather information about the planets and moons on their **Lesson 1 Planet Data Sheets** (SW pp.6-7). It will probably work best if small teams of students gather data on two planets. Then the class can complete their charts as a group. It also would be helpful to create a large classroom-size chart or to use a transparency to gather all of the data.

Notes:

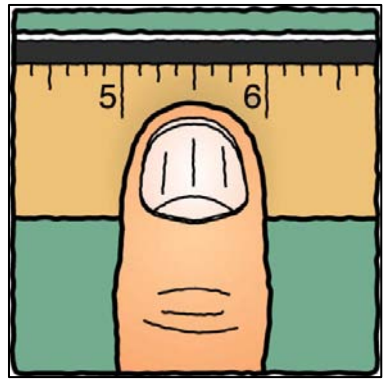
1. Encourage students to use the rollover vocabulary feature at the bottom of the WTD comparison window to learn words and definitions that are unfamiliar.

2. The moons are not listed on the Planetary Data Sheets; however, you can expand the requirements by having each group collect data on one moon. WTD contains data for the following five moons: the Moon, Europa, Io, Titan, and Triton.

3. On the Planetary Data Sheets there is a place to record two measurements of distance: one in kilometers (km) and the other in Astronomical Units (AU). The Astronomical Unit and its origin will be explained in the EXPLORE section of this lesson. If students do not recognize this unit, assure them that it will be explained later and that for now they just need to record the data.



3. MEASUREMENT



Now that students have gathered information about the planets, they need to have mathematical means of interpreting the data.

I. Activate students' prior knowledge of measurement

- In everyday life how do you use measurement?
- What do scientists measure?
- What do engineers measure?
- What is needed for measuring something? (A tool and a measurement unit)
- What tools do we use to measure with and what do the tools measure? (Example: measuring tape measures distance or dimensions)
- What are different types of units that are used to measure things?
- Where did our current measurement units come from?

II. Establish historical background of measurement

Have students read ***A Brief History of Units of Measurement*** (SW pp.8-10), and then host a class discussion using the five questions at the end of the article.

Resources used for *A Brief History of Units of Measurement* article:

http://www.unc.edu/~rowlett/units/custom.html

http://lamar.colostate.edu/~hillger/origin.htm

http://standards.nasa.gov/history_metric.pdf

III. Finding a method for converting units of measurement

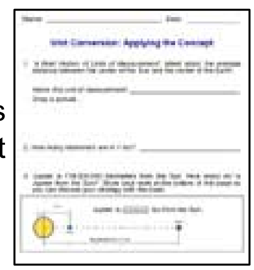
A.) Building the Concept: Converting from a Larger Unit to a Smaller Unit

Introduce students to the concept of unit conversion using the **Unit Conversion: Building the Concept** worksheet (SW p.11). Students who need more guidance can use the **Math Review: Converting Units** worksheet from the Pre-Lesson Activity (SW p.3, TG pp.10-16).


Unit Conversion: Building the Concept

Note: You can preface this activity by having students use their own ruler to determine the relationship between inches and centimeters. Students will likely obtain an estimate to 1 decimal place, e.g., 1 inch is approximately 2.5 centimeters. The relationship is estimated more closely as 1 inch is approximately 2.54 centimeters.

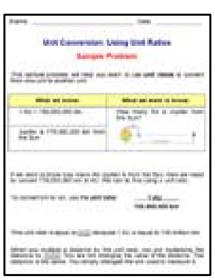
In solving the problems under part 2 of the worksheet, some strategies may have included multiplication to change inches to centimeters whereas others may have drawn lines (pictures) for measuring the centimeters and inches. These methods should get the same result, but what method should be used with greater distances? Students cannot draw kilometers and measure the equivalent amount of miles, so they will have to use multiplication and unit ratios when the numbers get larger.


Unit Conversion: Applying the Concept

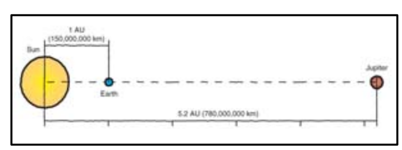
Now that students understand the relationship between two units (in this case: inches and centimeters), they can learn to use unit ratios to convert between them.

B.) Applying the Concept: Converting from a Larger Unit to a Smaller Unit

The student worksheet, **Unit Conversion: Applying the Concept** (SW p.12), draws on students' understanding of astronomical units and sets the stage for unit conversion between large numbers. Allow students to work their own solutions before sharing the **Using Unit Ratios** method in the Sample Problem (SW pp.13-14). By having students come up with their own methods first, they will build a conceptual understanding of the problem and will develop problem-solving skills rather than simply memorizing the steps.

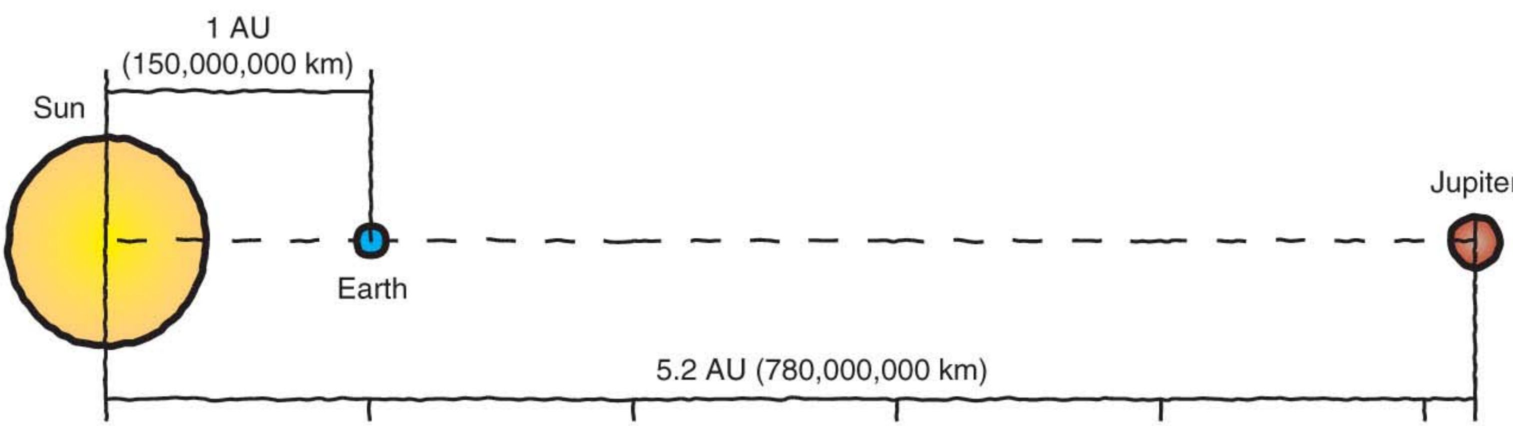

Unit Conversion: Using Unit Ratios
Sample Problem

Note: You may use **Transparency #4: Astronomical Units**, as a graphical means of understanding this unit (TG p.26).



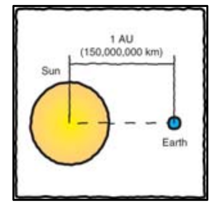
Note: Refer to the **Helping Students Communicate Math—Teacher's Resource** for advice on how to guide students' math communication of their problem solving strategies (EG p.x).

Transparency #4: Astronomical Units



How big is an AU?

The distance around the Earth at the equator (the circumference of the Earth) is 40,075 km. *How many times would you have to circle the Earth at the equator to travel 1 AU?*



We know that

1 AU = 150,000,000 km

We know that one trip around the Earth is

Circumference of the Earth = 40,075 km

So to answer the question, divide 150,000,000 km by the distance 40,075 km around the Earth.

$$\text{Number of Earth circumferences in 1 AU} = \frac{150{,}000{,}000\ \cancel{\text{km}}}{40{,}075\ \cancel{\text{km}}} = 3{,}743$$

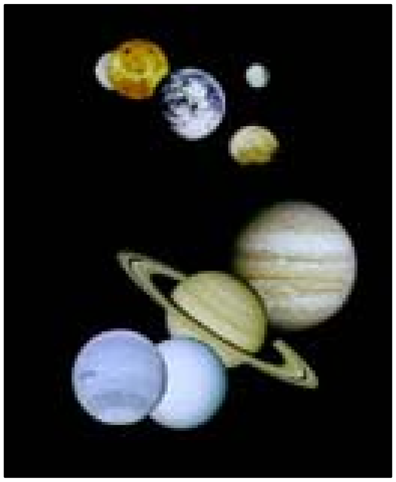
This means you would have to travel around the Earth at the equator 3,743 times to travel the distance of 1 AU.

Explain to the class that when you are trying to visualize something that is REALLY BIG, sometimes it is helpful to build a *scale model*. In a scale model, we make everything smaller by the same *proportional* amount.

For example, if we were making a scale model of the school and we used a shoebox for the office, could we use a soda bottle for a student? Why not?

If we used soda bottles to represent students, they would not fit in the same *scale*; they would not be in the same *proportion*. The students are going to build a scale model of the solar system. They will need to use some math to make sure that when we make smaller planets and orbits that we keep everything on the same *scale*, or in the same *proportion*.

4. ROUNDING, ESTIMATION, AND APPROPRIATE UNITS



When working with larger numbers, such as distances in the solar system or sizes of large planets, it is sometimes to our advantage to work with estimates obtained by rounding.

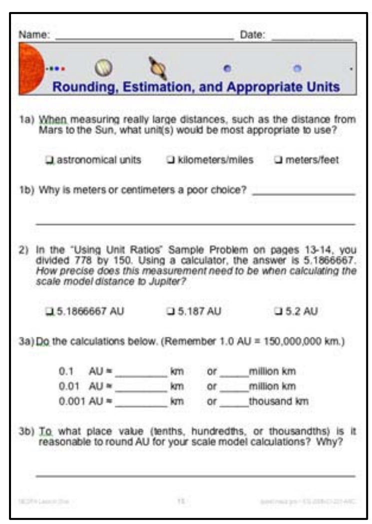
While advanced scientific methods and equipment are now able to derive distances accurate to the nearest tenth or hundredth place, it is rarely necessary to use that degree of accuracy when we are comparing distances as we are in this lesson.

In this lesson, we will use values of **AU rounded to the nearest tenth** and values of **kilometers rounded to the nearest whole number.** These approximations will be accurate enough for our purposes. Students should be aware of when they need to round their solutions. They should also understand how rounding affects the results of calculations, especially through multiple conversions and multiple roundings.

> **Note:** When we write a proportion using rounded values, we will use an equal sign even though the ratios that make up the proportion are rounded approximations.

Students should also be aware that the unit they choose to use affects the degree of accuracy of their measurement. For example, if they measure the length of a pencil, it would be more appropriate to use centimeters or inches instead of a decimal value in meters or yards. When measuring the distance from their house to the school, it would be appropriate to use kilometers or miles instead of using several thousand centimeters or inches.

The questions on page 15 of the student workbook can be used to help students think about selecting an appropriate measurement unit and approximation.



Name: ______________ Date: ______________

Rounding, Estimation, and Appropriate Units

1a) When measuring really large distances, such as the distance from Mars to the Sun, what unit(s) would be most appropriate to use?

❑ astronomical units ❑ kilometers/miles ❑ meters/feet

1b) Why is meters or centimeters a poor choice? ______________

2) In the "Using Unit Ratios" Sample Problem on pages 13-14, you divided 778 by 150. Using a calculator, the answer is 5.1866667. *How precise does this measurement need to be when calculating the scale model distance to Jupiter?*

❑ 5.1866667 AU ❑ 5.187 AU ❑ 5.2 AU

3a) Do the calculations below. (Remember 1.0 AU = 150,000,000 km.)

0.1 AU ≈ ________ km or _____ million km
0.01 AU ≈ ________ km or _____ million km
0.001 AU ≈ ________ km or _____ thousand km

3b) To what place value (tenths, hundredths, or thousandths) is it reasonable to round AU for your scale model calculations? Why?

SW = student workbook   TG = teacher guide   EG = educator guide

Lesson 1 – EXPLORE

- **Estimated Time**: 3 sessions, 40-50 minutes each
  - Session 1—Build a scale model of the solar system in terms of *size*
  - Session 2—Calculate the scale of the solar system model in terms of *distance*
  - Session 3—Walk the solar system model to understand both *size and distance*

- **General Materials**:
  - Transparency #5: Planetary Alignment (TG p.41)
  - *What's the Difference* (one in-class computer with projector is sufficient)

- **Clay Model Materials**: (acquire 1 set of items marked with a * for *each group* of students)
  - * 5 lbs of modeling clay <u>or</u> salt dough
  - * Plastic knives (for cutting clay)
  - * Paper plates (for carrying/storing clay)
  - * 10 index cards
  - 1-meter diameter object (inflatable ball or poster board)
  - 5 pieces of neon poster board cut in half for 10 signs
  - Markers
  - Tape
  - 10 stakes
  - 4 lengths of string measuring 43 m, 75 m, 107 m, and 161 m
  - 4 cardboard tubes (paper towel or toilet paper rolls) for wrapping string
  - Local map of the city or neighborhood

- **1000-Meter Model Materials**: (acquire 1 set of materials for entire class)
  - Bowling ball (or similarly sized playground ball)
  - 3 pinheads (preferably one smaller than the other two)
  - 2 peppercorns (1 black, 1 green)
  - 1 pecan
  - 1 hazelnut
  - 2 coffee beans
  - Binoculars (for walking the solar system)
  - 5 pieces of neon poster board cut in half for 10 signs
  - Markers
  - Tape
  - 10 stakes
  - 4 lengths of string measuring 10 m, 18 m, 25 m, and 38 m
  - 4 cardboard tubes (paper towel or toilet paper rolls) for wrapping string

<u>Recommended General Approach</u> (more detail is provided in the following pages)

Session 1—The focus of this session is to understand the sizes of the planets.

- Divide students into teams of 4 or 5 and have them follow the directions on page 15 to build a Clay Model of the solar system. You will need 5 pounds of clay (or salt dough), plastic knives, paper plates, and a set of 10 index cards for *each* team. Once the planets are molded, have each team label their nine planets with an index card and store the planets on paper plates. Label a 1-meter diameter object as the Sun.
- As a class, collect the household items required for the 1000-meter Model—one model will suffice for the entire class. (See page 20. If some items such as a bowling ball or hazelnut are difficult to come by, then items of similar size may be substituted.) Assign students to label the ten pieces of poster board as the Sun, Mercury, Venus, Earth, etc all the way to Pluto. Finally, have students tape each planetary item to the appropriate sign (for example: tape one of the pin heads to the sign labeled Mercury) and then tape each sign to one of the ten stakes.
- Discuss the model(s). How does the Clay Model compare to the items in the 1000-meter Model? If multiple clay models were built, how do they compare from one team to the next? Are the planets in the models perfectly spherical? Are the real planets in our solar system perfectly spherical?

Session 2 – The focus of this session is to calculate the distances that the model planets are from the Sun and to determine the distance scale of the model(s).

- Using ratio and proportion, students will calculate the distances of the nine model planets from the model Sun. You can choose to do this activity for only one of the models or you can divide the class into two teams and calculate the scale distances for both models. (*See pages 15-24 of the student workbook.*)
- The scale of the Clay Model is: 1 AU = 107 meters.
- The scale of the 1000-meter Model is: 1AU = 25.4 meters.

Note: http://www.exploratorium.edu/ronh/solar_system/ is a great web site from the Exploratorium. It allows you to input the size of the Sun for a model in either inches or mm, and it will calculate the scale size and distances for the planets.

Session 3 – The focus of this session is to understand size and distance together.

- Using the distances calculated in session 2, choose one of the models to "walk." (The 1000-meter Model is recommended because it is shorter.) Walk at least the inner planets and then use binoculars or a local map to visualize the outer planets.
- Discuss the model. Do the distances from the planets to the Sun change? Do the distances between planets change? Is there a pattern to the distances?

SESSION 1: CREATING A SCALE MODEL (Size)

Large sizes and distances are difficult to conceive. A scale model helps establish a sense of these sizes and provides a context for the rest of the lessons. There are several methods for building a scale model of the solar system that is accurate for both size and distance. This lesson includes two methods: 1) Clay Model and 2) 1000-meter Model.

Note: Both the Clay Model and the 1000-meter Model result in a model of the solar system that is to scale for both **size and distance**. For both models, students will only calculate the scale for distance because the scale for size has already been determined. *Teachers have the option of using either one of the models in their lesson or a combination of both models.* The Clay Model is excellent at providing a hands-on understanding of the sizes of the planets, whereas the 1000-meter Model is more practical for walking the solar system in terms of distance.

Method One: Clay Model

The Clay Model is a hands-on activity using modeling clay (or salt dough) to give students an eye-opening understanding of the sizes of the planets in our solar system. In this activity, students follow directions and repeatedly divide five pounds of clay (or salt dough) into tenths until a scale model of the nine planets is achieved in terms of size. Next, students calculate the distances that these planets would need to be spaced in order to make the model accurate in terms of distance. Finally students walk the solar system and place the planets at the distances they calculated. **Note:** The scale distance of this model places Pluto 4,205 meters (2.61 miles) from the Sun. For practical purposes, students can walk the distance of the inner planets (161 meters or 0.10 mile) and then refer to a local map to mark where the outer planets would be in relation to the Sun.

Method Two: 1000-meter Model

The 1000-meter Model requires students to collect small household items (bowling ball, beans, nuts, pinheads…or similarly sized objects) to quickly create a scale model of the solar system in terms of size. Next, students calculate the distances that these planets would need to be spaced in order to make the model accurate in terms of distance. Finally students walk the solar system and place the planets at the distances they calculated. The scale distance of this model places Pluto 998 meters (0.62 miles) from the Sun—hence the name 1000-meter Model. If school premises (or time) do not allow students to walk the full 998 meters, then signs for the outer planets can be pre-positioned in the neighborhood and students can walk the distance of the inner planets (38 meters or 0.02 mile) and then use binoculars to view the outer planet signs.

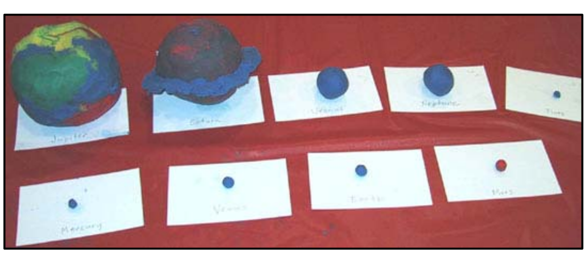
Clay Model

The following model was created by Dennis Schatz from the Pacific Science Center in Seattle for the Family Astro Program of the Astronomical Society of the Pacific. Modeling clay or salt dough may be used for this activity.

Note: Modeling clay is more expensive but holds its shape better and is less messy than salt dough. However you can tie-in chemistry and measurement to the lesson if you have students make salt dough in the classroom. (salt dough recipe: http://www.gigglemoose.com/salt_dough_recipe.htm)

Note: The Sun's diameter is approximately 10 times that of Jupiter. For the clay model, the Sun would have a diameter of about 1 meter. If it is not possible to find an inflatable ball of that size, a paper or poster board model will suffice.

Hint: Use five 1-lb boxes of clay. Each box has 4 bricks of clay for a total of 20 bricks, which is easily dividable by 10!



QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Creating a Clay Model of the Solar System

MATERIALS – 9 index cards
– Marker
– 5 pounds of modeling clay (or salt dough)

DIRECTIONS Using a marker, label the 9 index cards with the names of the 9 planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. Then using 5 pounds of modeling clay, follow the 7 steps listed below.

Step 1. **Divide the clay into tenths.**

- Use 6 tenths to make Jupiter.
- Use 3 tenths to make Saturn.
- Use the remaining clay (1 tenth) in step 2.

Step 2. **Divide the remaining clay into tenths.**

- Add 5 tenths to Saturn.
- Use 2 tenths to make Uranus.
- Use 2 tenths to make Neptune.
- Use the remaining clay (1 tenth) in step 3.

Step 3. **Divide the remaining clay into tenths.**

- Add 9 tenths to Saturn.
- Use the remaining clay (1 tenth) in step 4.

Step 4. **Divide the remaining clay into <u>halves</u>.**

- Use 1 half to make Earth.
- Use the remaining clay (1 half) in step 5.

Step 5. **Divide the remaining clay into tenths.**

- Use 9 tenths to make Venus.
- Use the remaining clay (1 tenth) in step 6.

Step 6. **Divide the remaining clay into tenths.**

- Use 9 tenths to make Mars.
- Use the remaining clay (1 tenth) in step 7.

Step 7. **Divide the remaining clay into tenths.**

- Use 9 tenths to make Mercury.
- Use the remaining clay to make Pluto.

ASSESSMENT:

When you finish making your 9 planets, you should double-check your work!

Use a metric ruler to measure the *diameter* of your clay planets in millimeters (mm).

The diameter of your planets should be close to the "*scale diameter*" measurements in the chart on **page 20** of the student workbook.

Creating a 1000-Meter Model of the Solar System

The items below are suggested for the 1000-meter Model, which comes from Mission Mathematics by Vincent O'Connor and Michael Hynes. If certain items cannot be obtained, then items of similar size may be substituted. *(The pictures below are not to scale.)*

Body		**Scale Model Object**	**Scale Model Size**
Sun		bowling ball	235 mm
Mercury		regular pin head	0.8 mm
Venus		green peppercorn	2.0 mm
Earth		black peppercorn	2.1 mm
Mars		regular pin head	1.1 mm
Jupiter		pecan	24.1 mm
Saturn		hazelnut	20.4 mm
Uranus		coffee bean	8.6 mm
Neptune		coffee bean	8.4 mm
Pluto		small pin head	0.4 mm

Planet Shapes

Misconception Alert!

Many students may think that the planets are perfect spheres. They are often shown as perfect spheres in pictures or models. The following discussion may give you an opportunity to discuss the fact that the planets are not perfectly spherical. This notion will also be addressed in Lesson 2.

Some students might point out that the planet models are not perfect spheres (this will be the case for either the Clay Model or the natural objects in the 1000-meter Model.) In actuality, the planets are not perfect spheres. Asteroids are a good example of objects orbiting the Sun that are not spherical. Students can be shown a topographical globe. When the Earth is studied up close, you see that it is a rough, bumpy, rocky planet and not a smooth, perfect globe.

Asteroids

Misconception Alert!

In many science fiction movies asteroid fields are dangerous areas where ships dodge in and out of flying rocks. This has led to the misconception that the asteroid field in our solar system is a dense area of floating debris that would pose a hazard for crew vehicles or probes traveling to the outer planets. Adding asteroids to the scale model as described below could help correct this misconception. Be sure to explain to the students that the crew vehicles NASA uses would be MUCH smaller than a grain of sand in this model, so the spacing of the asteroids, given the size of passing vessels, does not pose much of a threat. Another way to address this misconception is to ask the students to consider ships on the oceans. At any given time, there are many thousands of ships at sea. This number may seem large (as does the number of asteroids orbiting the Sun), but collisions at sea rarely occur.

Asteroids range from approximately 1 to 1,000 km in diameter. In our solar system, the main belt of asteroids orbits at approximately 2 to 4 AU. For the Clay Model the scaled size of the LARGEST asteroids would be approximately 0.7 mm (roughly the size of an average grain of sand), and the main belt in the Clay Model would range from 214 to 428 meters away from the Sun.

To model the size and spacing of asteroids in the Clay Model, have the students place 1 average size grain of sand per 248 square centimeters (1 grain of sand in a 15.7 cm by 15.7 cm square.) It is estimated that there are 1.5 million asteroids in the main belt, but having the students place a few within the correct area will suffice.

SESSION 2: FINDING THE SCALE OF THE MODEL (Distance)

One goal of this lesson is for students to determine the scale of a model of the solar system. You can make a connection to students' experience with maps. Most maps have a scale on them that shows how many miles or km are represented by an inch or a cm on the map. (If possible, show examples on maps or on a globe.) There are many ways to represent the scale of a model. Students can use ratios or other methods to find multiple answers.

Mathematical Example: A typical classroom globe is about 35.5 cm (14 inches) in diameter. The diameter of the Earth is 12,755 km.

In this scale model (the globe), how many kilometers are represented by 1 centimeter?

$$\frac{\text{Diameter of the Earth}}{\text{Diameter of the globe}} = \frac{12{,}755 \text{ km}}{35.5 \text{ cm}}$$

If x stands for the number of kilometers represented by 1 centimeter, we have

$$\frac{12{,}755 \text{ km}}{35.5 \text{ cm}} = \frac{x}{1 \text{ cm}}$$

To solve for x, we cross multiply.

$$12{,}755 \text{ km} \bullet 1 \text{ cm} = x \bullet 35.5 \text{ cm}$$

To isolate x, we divide both sides of the equation by 35.5 cm.

$$\frac{12{,}755 \text{ km} \bullet 1 \cancel{\text{cm}}}{35.5 \cancel{\text{cm}}} = \frac{x \bullet \cancel{35.5 \text{ cm}}}{\cancel{35.5 \text{ cm}}}$$

We continue to solve for x by dividing 12,755 km by 35.5.

$$\frac{12{,}755 \text{ km}}{35.5} = x$$

$$359 \text{ km} = x$$

By dividing 12,755 km by 35.5, we find that **359 km is represented by 1 cm**, OR we can say that 1 km is represented by approximately 0.003 cm.

Exploring Methods For Finding Scale

Before teaching students to use ratios to calculate scale, ask them how they can find that relationship. Allow students to work together using calculators if necessary. After some groups have found a solution, have them share the result with the class. Ask:

- How did they find the solution?
- How do they know it is right?
- Does their answer makes sense? For example, should the distance from Jupiter to the Sun be longer or shorter than the distance from Pluto to the Sun?

Some students may see that 1,000 (or 4,205 for the Clay Model) divided by 39.3 will give the value of 1 AU in meters for the model. If they can make that connection, then they can use that relationship to find the distance to all of the planets.

Using Ratios For Finding Scale

Using the **Calculating Scale of the Model, Part I** student worksheet (*pages 17-19 or 22-24 in the student workbook.*) teach students how to calculate scale using ratios. Then, once students have calculated that 25.4 meters represent 1 AU in the 1000-meter Model (and 107 meters in the Clay Model), they can apply this scale to the other planets by setting up ratios using the distances given in AUs that they collected from *What's The Difference*.

> **Note:** If 25.4 meters is used for 1 AU in the 1000-meter Model and the AU are rounded to the nearest whole meter when pacing out the course, then Pluto will actually be at a distance of 998 meters instead of 1,000 meters. If students catch this, explain that this is a result of rounding numbers.

> **Note:** Students can solve for one or all of the scale distances. It might save time to assign each planet to a small group. If they use ratios and proportions, ask them what type of math they are using. Some students will make the connection that they are just multiplying the unit ratio (25.4 meters per 1 AU or 107 meters per 1 AU) by the distance from the planets to the Sun in AU. This simply becomes a conversion problem.

Students should record the scale distances for all of the planets in Column A of the **Calculating Scale of the Model, Part II** student worksheet (*p.20 or 25*). Then, to prepare for session 3 (walking the solar system), have students convert their model distances from meters to *half-meter paces* by multiplying all answers by two. The half-meter paces will be recorded in Column B of the **Calculating Scale of the Model, Part II** student worksheet.

SESSION 3. WALKING THE SOLAR SYSTEM (Size and Distance)

Once the class has made or collected their scale models (either objects or clay planets) and they have calculated the distance from each planet to the Sun using the unit ratio, they are ready to travel through the solar system.

If signs were not made in session 1, then have students use markers, neon poster board, and stakes to make 10 large signs with the names of the planets written largely and clearly. The signs will be placed next to the Sun and planets during the walk so that students can look back and see the location of their objects, even if they cannot see the actual object without magnification.

As learned in session 2, the 1000-meter Model places Pluto at approximately 1,000 meters away from the Sun, and the Clay Model places Pluto approximately 4,200 meters away. In planning this unit, it might be helpful to measure out some distances at the school or in the neighborhood. The total distance walked from the Sun to Pluto is 0.62 miles for the 1000-meter Model and 2.61 miles for the Clay Model. If it is possible to measure the distance in a fairly straight line, then use a pair of binoculars to help students attempt to see the other planets in the model as they get farther away from the Sun.

According to Mission Mathematics, a yard is the average "pace" for a person. A meter is slightly longer. It would be best to have the students practice taking HALF-meter steps. (The number of paces will be twice the number of meters as was calculated in session 2.)

Choose a starting place and count out the number of paces starting from the Sun. At each stop, place the planet and its sign and have the class look back at the previous object. To see the object itself, students may need binoculars. Before leaving for the next planet, announce the number of steps (it is fun to have the class count along).

Note: The 1000-meter Model will take the students 0.62 miles away from the Sun. The Clay Model is longer at 2.61 miles. If it is not feasible to walk the entire distance, then it is useful to mark local landmarks or locations on a map or in a line of sight. Once you reach a point where you cannot travel further, it is important to point out how many more steps it would take to get to the rest of the planets. If possible, try to get as far as Jupiter or Saturn, as the jumps in the distances between those planets really emphasize the full size of the solar system.

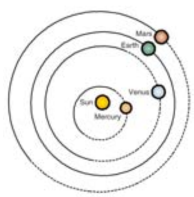
Planet Locations

After pacing out the entire system (or going as far as possible), return to the four inner planets in the model. The planets should be in a line, following the path of the paces taken away from the Sun. Leaving the planets lined up, ask the students:

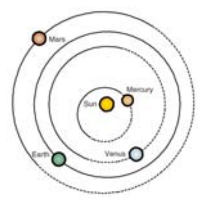
– What might be wrong with the model?

– How does the model differ from how the planets actually look in the solar system?

One of the limitations of the model is that it is EXTREMELY rare that all of the planets are lined up. The last time the planets were even close to being lined up was over 1,000 years ago, and they are not predicted to be close again for another 400 years. Use **Transparency #5: Planetary Alignment** (*see page 41*) to discuss with students which is a more realistic view of the solar system and why.



vs



If time permits, use four lengths of pre-measured string attached to the Sun to outline the orbits of the four inner planets. Have four students each take one of the ends of the four strings and walk away from the Sun until the strings are taut. The student with the shortest string should end up next to Mercury and the student with the longest string should end up next to Mars. Depending on the model used, the four lengths of string will measure according to the table below:

String Lengths

1000-meter Model		Clay Model
10 meters	Mercury	43 meters
18 meters	Venus	75 meters
25 meters	Earth	107 meters
38 meters	Mars	161 meters

Instruct the four students at the ends of the four strings to move varying distances away from their respective planets along their orbital paths (keeping the strings pulled taut from the stake will ensure proper orbital arcs). This movement will represent the planets in more realistic positions.

Note: You can use http://space.jpl.nasa.gov/ to get the actual location of the planets on the day you conduct this lesson if you choose. (Select Show Me "The Solar System" as seen from "above." To view the inner planets, select I want a field of view of "5" degrees, then select the "orbits" and "extra brightness" options above the "Run Simulator" button.)

Ask students to notice the planets' paths around the Sun.

- Does the distance of the planets from the Sun change much during their orbit? (No)
- What about the distance from each planet to another? Does that change? (Yes)

The students should realize that the planets are moving around the Sun at different rates. Use a single in-class computer and projector to show the **orrery** (model of the relative planetary positions) in *What's The Difference* to the whole class to help them visualize this fact.

Note: To access the *What's The Difference* **orrery** tool:

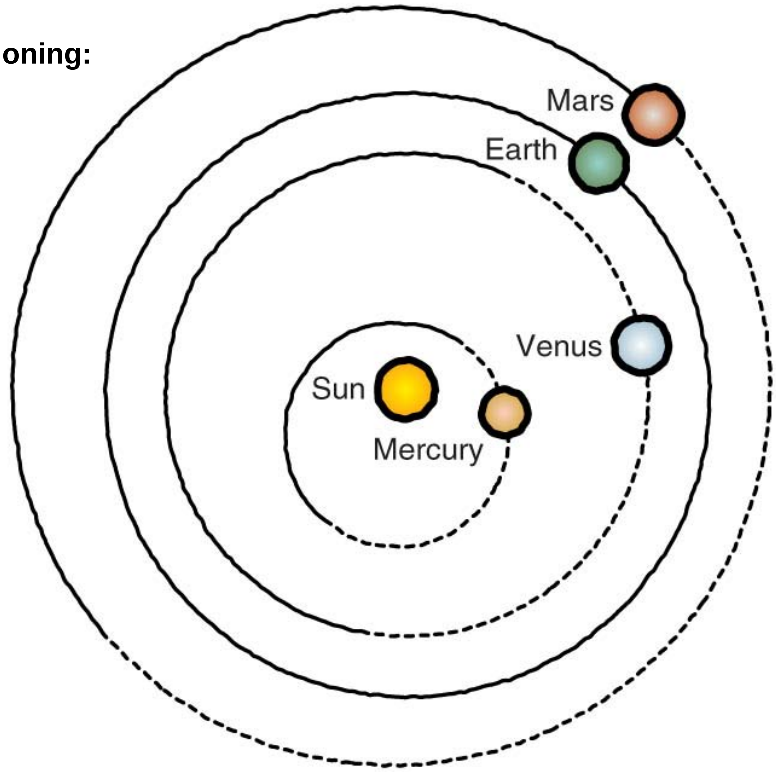
1. Open *What's The Difference* solar system data set.
2. Click the blue "Tools" button located in the right margin.
3. Click "Orrery" in the Tools pop-up window.

Critical Thinking

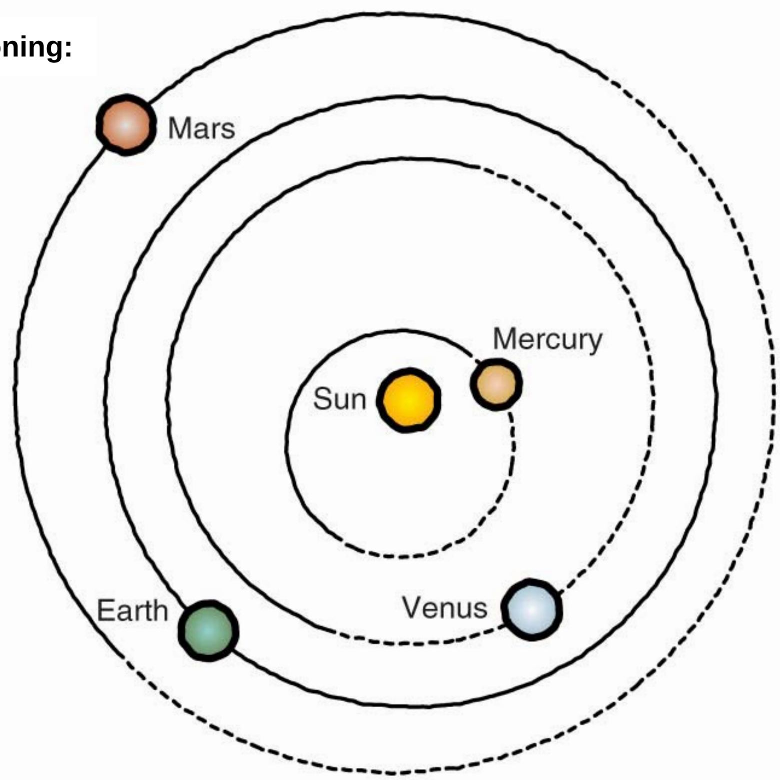
Explain to the students that the distance between the planets changes constantly because they are all moving at different speeds around the Sun. This is a challenge that NASA has to address any time they plan a mission to another place in the solar system. The students will learn more about this problem and how to solve it in Lesson 3. To get the students thinking about it, ask them the following: *If everything is moving, how can we land on the planet or moon we are attempting to reach?*

Transparency #5: Planetary Alignment

Extremely rare positioning:



More realistic positioning:



SW = student workbook   TG = teacher guide   EG = educator guide

Lesson 1 – EXPLAIN

- **Estimated Time**: 1 session, 40–50 minutes
- Materials:
  - Think About It student worksheet (SW p.26)
  - Graphing Resource—Student Guide (SW pp.27-30)
  - Graphing the Solar System student worksheet (SW p.31)
  - Helping Students Communicate Math—Teacher's Resource (EG p.x)
  - Graphing Rubric (TG p.46)
  - Graph paper or chart paper

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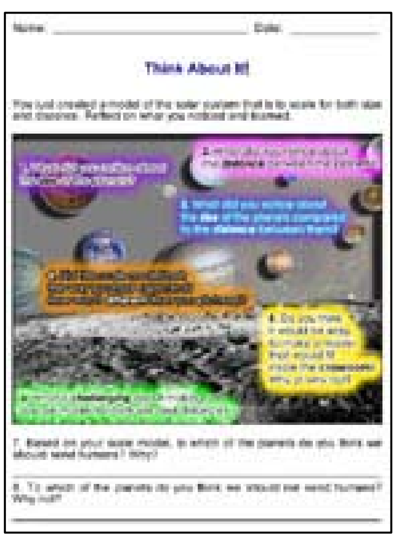
1. REFLECTION

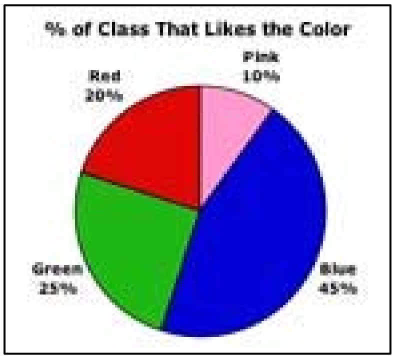
Now that students have "traveled" the solar system (or a portion of it), they should reflect on and share what they learned and observed. Use the eight questions on the student worksheet titled **Think About It** (SW p.26) to lead a class discussion or to serve as a written reflection on the scale model(s).

When responding to questions 7 and 8, students should consider all that they have learned including the data they recorded on the **Planetary Data Sheets** (SW pp.6-7) in the ENGAGE portion of the lesson.



Note: It is important to have the students reflect on the scale model soon after it has been built. The impact of the distances is an important part of the lesson, so this reflection should take place immediately or soon after the EXPLORE sessions.

2. GRAPHING: ANOTHER WAY TO SHOW RELATIONSHIPS



After walking the students though the model, ask them if they can think of another way to show the relationship between the distances between the planets. Graphing is one way to show this relationship between numbers.

Students will work in groups to graph the distances between the planets. They will use the **Graphing Resource—Student Guide** (SW pp.27-30) and the **Graphing the Solar System** worksheet (SW p.31) to answer five questions as they work:

- 1. What type of graph will you use?
- 2. What units will you use?
- 3. What scale will you use?
- 4. What are the maximum and minimum values on your graph?
- 5. Will your graph start at zero?

This activity will encourage the use of problem-solving skills. Students will need to experiment with the graphs and numbers to see what works best. They will need to communicate their choices and explain how they made their decisions when they share their graph with the class.

Review the **Graphing Resource—Student Guide** with the class before beginning the activity. Students should use this resource along with the data set they choose in order to help them make an appropriate choice of graph. Each graph must have appropriate labels, titles, and use an appropriate scale, as described in the Graphing Resource. Have each group complete a rough draft or a sketch for you to check before they make a final copy on poster or chart paper. Also, refer to the **Helping Students Communicate Math—Teacher's Resource** (*see the Educator Guide*) for advice on how to guide the students' math communication of their graphing solutions.

When each group is done with their graph, have the students share their graphs with the class and explain why they made the choices that they did. Line graphs, scatter graphs, or bar graphs would all probably be equally effective in showing the distances between the planets. Students can compare graphs and note the similarities and differences between the different representations.

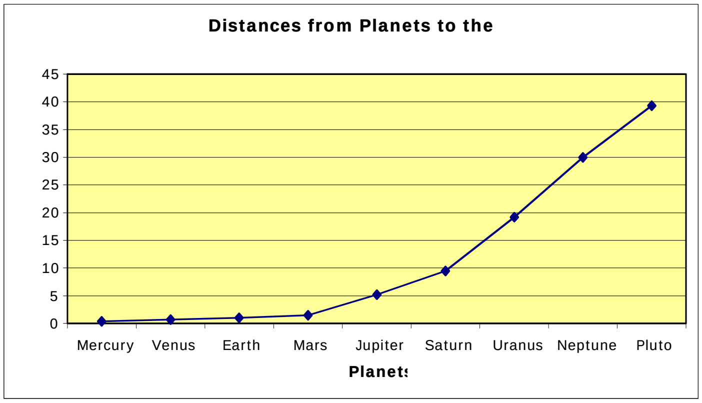
Student graphs may be assessed using the **Graphing Rubric** (TG p.46).

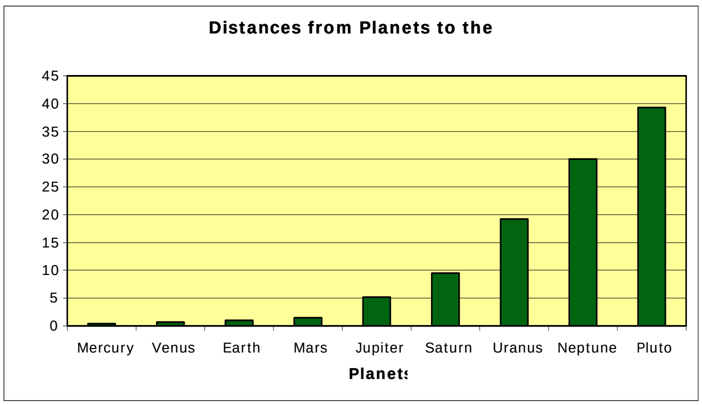
Ask the following questions to ensure that each group communicates all of the important information:

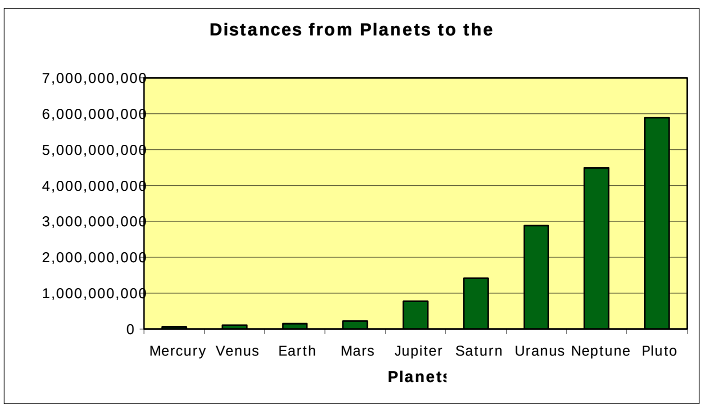
- How did you decide to use this particular data set and graph? Explain.
- How do you know your graph is accurate?
- Do other students have questions about how you graphed the data? Does anyone disagree with your graph?
- Does your graph make sense? (For example, does Pluto stand out as the planet that is the furthest away?)
- How do different students' strategies for graphing the data compare? Which strategy do you like best? Why?

Ask students to share what they notice about the distances and how the graphs represent the distances in the solar system. They should reflect on the fact that as we travel further out in the solar system, the distances between objects increase greatly. The students can study this phenomenon in more detail in the EXTEND section of the lesson. (*See pages 50-55.)*

Answer Key: Possible Graphs







Graphing Rubric

Assess student graphs and presentations with this rubric:

4	• All data is graphed extremely accurately. Decimals and fractions are taken into account. • Graph is titled and all axes are correctly and neatly labeled. • Graph includes a consistent scale on the y-axis. • Graph type is appropriate for data used. • Choices for graph type, scale, and units are fully justified and related to the data.
3	• All data is graphed accurately. Decimals and fractions were rounded to whole numbers. • Graph is titled and all axes are labeled. • Graph includes a consistent scale on the y-axis. • Graph type is appropriate for data used. • Choices for graph type, scale, and units are justified and may be related to the data.
2	• Data is graphed somewhat accurately. Decimals and fractions were ignored. • Graph is missing either title or axis labels. • Graph includes a consistent scale on the y-axis. • Graph type is somewhat appropriate for data used. • Choices for graph type, scale, and units are not justified and/or may not be related to the data.
1	• Data is not graphed accurately. • Graph does not have a title or axis labels. • Graph does not have a consistent scale for y-axis. • Graph type is inappropriate for data used. • Choices for graph type, scale, and units are not justified and are not related to the data.

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Lesson 1 – EVALUATE

- **Estimated Time**: 1 session, 30-40 Minutes
- Materials:
  - Student work from Pre-Lesson Activity
  - So What Do You Think student worksheet (SW p.32)
  - Problem Solving Rubric (TG p.49)

A **Problem Solving Rubric** is provided to help evaluate students' work in this lesson. (TG p.49)

To reflect on and review Lesson One, use the "Check for Understanding" and "Reflection" questions to lead the class in a discussion. Or to formally assess learning, pull questions from the list to use in a test or quiz.

Check for Understanding:

1. What are the parts of our solar system and how do they compare?
2. Describe the location and nature of the Sun.
3. Describe and compare different measurement systems.
4. How are measurement systems determined?
5. What measurement units are used to measure length, distance, speed, volume, mass, etc?
6. What is an AU? How big is it?
7. Why do scientists use AU?
8. How do the planets vary in size?
9. What happens to the distance between the planets as we travel away from the Sun?
10. Are the planets lined up frequently? Why or why not?

Note: This would be a great opportunity to have the students look at their pre-lesson pictures, knowledge, and questions and have them reflect on how much they have already learned about our solar system.

Reflection:

1. What do you think are the best units for measuring our solar system?
2. What did you learn about making scale models?
3. Did anything surprise you about the scale model?
4. Why is it challenging to create a real scale model of the solar system?
5. Are most pictures or models of our solar system that you have seen accurate?
6. Why do you think traveling to the outer planets is difficult?
7. Was there any other new or interesting information that you learned?
8. What new questions do you now have about our solar system and the planets?

Preparing to move on:

In Lesson 2, students will look at the mass, density, gravity, and composition of the planets. The following brief closing assignment will help you segue into the next lesson.

Page 32 in the student workbook can be given as a brief, one paragraph writing assignment, or students can respond on index cards (keeps responses concise) or on the **So What Do You Think** student worksheet. Alternatively, students can discuss their answers in pairs or small groups and report their answers back to the class.


Name: ____________________ Date: __________

So What Do You Think?

Now that you have collected data on the planets, built a scale model of the solar system, and graphed the distances of the planets from the Sun, take a moment to think about what you have learned.

1. What did you learn from *What's the Difference*, the scale model, and your graph?

2. Based on the scale model and what you have learned, to which planet or moon do you think we should send humans in our solar system? Why?

3. What else do you need to know about the planets and moons in order to make a recommendation?

Problem Solving Rubric

Assess problem solving assignments and presentations with this rubric:

4	• Answers were calculated correctly to an appropriate degree of accuracy (rounded to a decimal place or whole numbers where specified). • Answers are fully explained and justified in detail. • All steps of the problem are explained in detail. • Information supplied by students is accurate and the source of the information is given. • Picture that accompanies problem is relevant, labeled, and demonstrates how the problem was solved. • Written explanation completely outlines the problem and the solution.
3	• Answers were calculated correctly, but to an inappropriate degree of detail (rounded to whole numbers or not rounded where appropriate). • Answers are explained and justified. • All steps of the problem are explained. • Information supplied by students is accurate, but the source of the information is not given in detail. • Picture that accompanies problem is somewhat relevant, may or may not be labeled, and somewhat demonstrates how the problem was solved. • Written explanation outlines the problem and the solution.
2	• Answers were mostly calculated correctly. • Answers are stated clearly but not explained or justified • All steps of the problem are not fully explained. • Information supplied by students may not be accurate and the source of the information is not given. • Picture that accompanies problem is not relevant, is not labeled, or does not demonstrate how the problem was solved. • Written explanation does not clearly outline the problem and solution.
1	• Answers were not calculated correctly. • Answers are not stated clearly and are not explained or justified. • Steps of the problem are not explained. • Information supplied by students is not accurate. / No picture. • Written explanation does not outline the problem or the solution.

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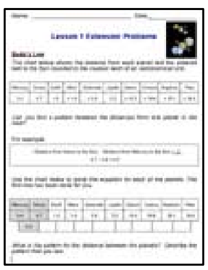
Lesson 1 – EXTEND & APPLY (optional portion of lesson)

- **Estimated Time**: 1 session, 30–40 minutes
- Materials:
  - Lesson 1 Extension Problems (SW pp.33-39)
  - Problem Solving Teacher Resource (TG pp.53-55)
  - Paper for student work
  - Rulers, tape measures, yardsticks or metersticks
  - (Optional) Calculators



Have students work on the **Lesson 1 Extension Problems**. (SW pp.33-39) These problems are multi-step open-ended challenges. Some will require the students to measure lengths inside the classroom and then apply what they know about scale and ratio and proportion. Students may choose the units they work with, as long as they are appropriate. The problems can be done individually, in groups, or as a class.

You may want students to accompany each solution with a written and graphical explanation of how the problem was solved. Review the **Problem Solving—Teacher's Resource** and the Scale Movie Stars example with your students before having them complete their own write up. (TG pp.53-55)

Note: Problem 1.a of the Extension Problems is used as the example write-up in the Problem Solving Resource. Review this example with your class. Then complete a write-up for problem 1.b together as a class. Students will be more comfortable with the format if it is modeled for them before they attempt it alone.

1. BODE'S LAW

Note: Bode's Law was actually discovered by Johann Titius in the eighteenth century, but was popularized by Johann Bode. Bode's Law is not really a law; it is merely an interesting relationship between the arrangement of the planets around the Sun. *In fact, it is based on **rough estimates** of planetary distances (at least as good as the measurements could be in the 1700s), so the actual orbital distances that the students calculate in other parts of this lesson will be somewhat different than the values listed here.* You may need to explain this to your students if there is potential for confusion based on the rounded numbers students used for the scale and graphing portion of this lesson.

Have students examine the chart in the Lesson 1 Extension Problems that shows the distance from each planet and the asteroid belt to the Sun. *This chart uses Astronomical Units rounded to the nearest tenth and is based on **rough estimates** of the planetary orbital distances.*

Mercury	Venus	Earth	Mars	Asteroids	Jupiter	Saturn	Uranus	Neptune	Pluto
0.4	0.7	1.0	≈ 1.6	≈ 2.8	5.2	≈ 10.0	≈ 19.6	≈ 30.1	≈ 39.6

Ask students to look at the differences between the distance from one planet to the Sun and the next and see if they can find a pattern between the distances.

For example:

Distance from Venus to the Sun – Distance from Mercury to the Sun = _?_

0.7 – 0.4 = 0.3

Solve this equation for each of the planets and have students describe the pattern.

Mercury	Venus	Earth	Mars	Asteroids	Jupiter	Saturn	Uranus	Neptune	Pluto
0.4	0.7	1.0	1.6	2.8	5.2	10.0	19.6	30.1	39.6
	0.3	0.3	0.6	1.2	2.4	4.8	9.6	10.5	9.5

Pattern: From Venus to Uranus, the distance from one planet to the Sun is about twice as much as the previous planet.

Note: The pattern actually continues to Pluto, if Neptune is removed, since the distance between Uranus and Pluto is 20 AU, which is about two times 9.6 AU. Since the law of doubling distances does not apply universally and without variation, it is not clear if it is an indication of a physical phenomenon. No reason for the pattern has been discerned. Some scientists think that Neptune and Pluto might have moved from their original positions at formation, but there is not enough evidence to support this theory.

In reality, the pattern is more complex than presented here. The original pattern can be described as follows:

- List the numbers, doubling every number after 3. (0, 3, 6, 12, etc.)
- Add 4 to each number. (4, 7, 10, 16, etc.)
- Divide each of the resulting numbers by 10. The results are the approximate distances of the planets from the Sun measured in AU. (0.4, 0.7, 1.0, 1.6, etc.)

Go over the “Background” of Bode’s Law located on the student worksheet as a class.

Have students complete the rest of the “Extra” Lesson 1 Extension Problems and discuss solutions as a class.

Note: The following is an optional extension for the AFUs (Absolutely Fabulous Units) problem. Students can exchange systems and ask other class members to use their system of measurement. Students can also use information provided in *What’s the Difference* to compare their unit to AU and then determine how many trips is THEIR unit between New York and Los Angeles?

Problem Solving

Teacher's Resource

During the course of this unit, students will be presented with multi-step, open-ended challenges. The problems can be solved in a variety of ways, and there will often be multiple solutions. The problems can be done individually, in groups, or as a class.

Each problem can be accompanied by a written explanation and a picture explaining how the problem was solved. Students can use the following outline to explain their work in written form:

1. Restate the problem. What are you trying to find out?
2. What information do you have? What information do you need to find your answer? Explain how you got the information and record it.
3. Estimate what you think the answer will be. How do you know your estimate is reasonable?
4. Show your work. Include all calculations you made in order to solve the problem—even the ones that did not work.
5. Explain HOW you solved the problem. Step-by-step, what did you do? Use transitions like first, next, then, and finally.
6. State your answer. Explain HOW you know it is correct. Does it make sense? Why?
7. Draw a picture to go along with the problem. Label sizes and distances.

When you finish, read over your work. Is it clear? Does it make sense? Pretend you are explaining this problem to someone younger than you. Did you explain the problem and the answer well?

Example: Scale Movie Stars

Some fantasy characters, such as Hobbits from Lord of the Rings, or Hagrid from the Harry Potter series are on different scales than humans. The following calculations will demonstrate how an everyday object would need to be changed to fit the scale size of a character.

Hobbits are known as Halflings. They are about half the size of a human. Hagrid, however, is half-giant because he had a Giantess Mother. He is about twice the size of a human.

If your teacher became a Hobbit, estimate how tall he or she would be. Estimate how tall your teacher would be if he or she were Hagrid's size. Measure your teacher and calculate his or her Hobbit and Hagrid heights. If possible, mark the Hobbit height, Hagrid height, and actual height of your teacher on the wall or chart paper.

Sample Write Up:

1. I am going to calculate the height my teacher would be if she was a Hobbit or if she was a half-giant like Hagrid.

2. I know that Hobbits are half the size of humans, and I know that Hagrid is twice the size of a human. In order to solve the problem, I need to know my teacher's height. I will use a meter stick and measure her. My teacher is 1.75 meters tall.

3. I estimate that as a Hobbit my teacher will be less than a meter tall because Hobbits are much smaller. I think that as Hagrid my teacher will be over 3 meters tall because Hagrid is much bigger.

4.

	Hobbit Height:	Hagrid Height:
1.75 meters • ½ = teacher's Hobbit height		1.75 m • 2 = teacher's Hagrid height
1.75 meters • 0.5 = 0.875 m		1.75 m • 2 = 3.5
Answer: *My teacher's Hobbit height = 0.875 m*		*My teacher's Hagrid height = 3.5 m*

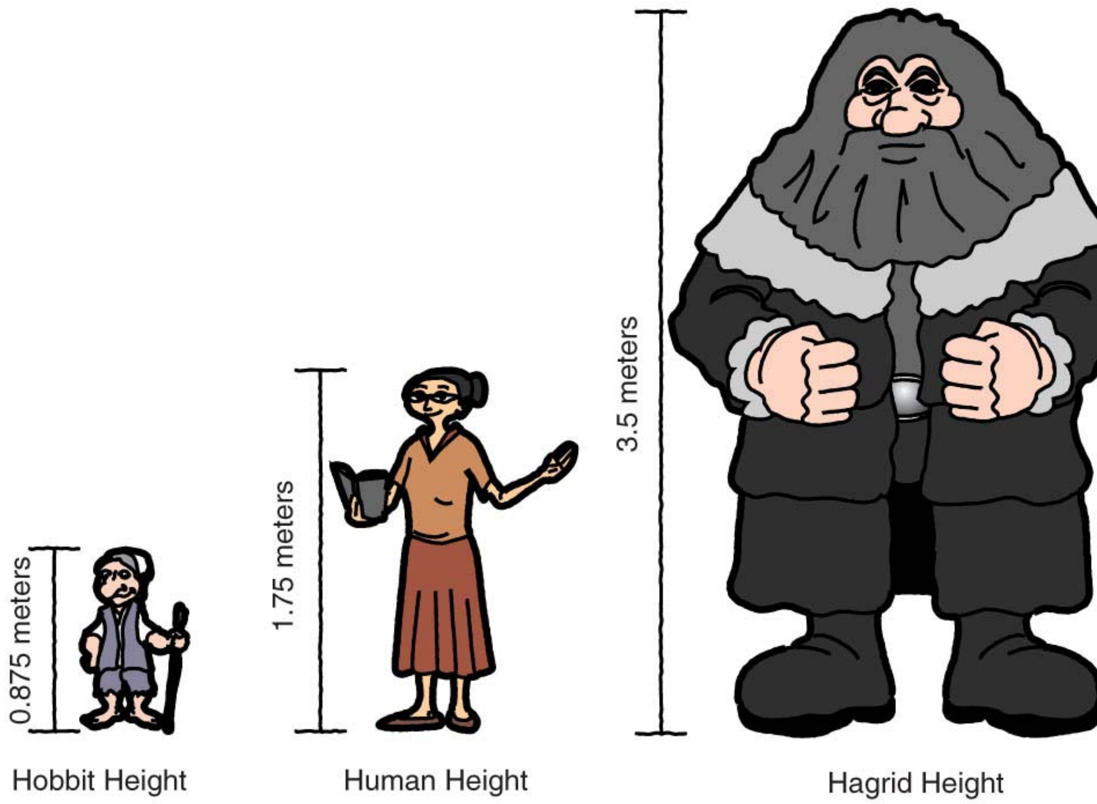
5. I solved the first part of the problem by multiplying my teacher's height by one-half. I solved the second part of the problem by multiplying my teacher's height by two.

First, I solved for her Hobbit height. Hobbits are half the size of humans, so to get my teacher's Hobbit height I multiplied her normal height by one-half. I decided it would be easier to multiply decimals, so I multiplied 1.75 meters by 0.5 because ½ is equal to 0.5.

Next, to get my teacher's Hagrid height, I multiplied her normal height by 2, because Hagrid is twice the size of a human.

6. I found that if my teacher were a Hobbit, she would be 0.875 meters tall because this is one-half of her normal height. I also found that if my teacher were like Hagrid, she would be 3.5 meters tall because this is two times her normal height. This makes sense because as a Hobbit she would be much smaller than her normal size, and as Hagrid she would be much bigger than her normal size. My estimates were pretty close. I was not off by that much.

7.



0.875 meters 1.75 meters 3.5 meters